In situ acoustic methods to estimate the physical and mechanical aging of oriented strand board

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Abstract Following the success achieved in previous research projects using non-destructive methods to estimate the physical and mechanical aging of particle and fibre boards, this paper studies the relationships between aging, physical and mechanical changes, using non-destructive measurements of oriented strand board (OSB). 184 pieces of OSB board from a French source were tested to analyze its actual physical and mechanical properties. The same properties were estimated using acoustic non-destructive methods (ultrasound and stress wave velocity) during a physical laboratory aging test. Measurements were recorded of propagation wave velocity with the sensors aligned, edge to edge, and forming an angle of 45 degrees, with both sensors on the same face of the board. This is because aligned measures are not possible on site. The velocity results are always higher in 45 degree measurements. Given the results of statistical analysis, it can be concluded that there is a strong relationship between acoustic measurements and the decline in physical and mechanical properties of the panels due to aging. The authors propose several models to estimate the physical and mechanical properties of board, as well as their degree of aging. The best results are obtained using ultrasound, although the difference in comparison with the stress wave method is not very significant. A reliable prediction of the degree of deterioration (aging) of board is presented.

Key words Oriented strand board, stress wave velocity, acoustic measurements, ultrasound measurements, mechanical properties, physical properties, aging tests.

1. INTRODUCTION

Many non-destructive methods are commonly used to estimate the physical and mechanical properties of wood and wooden products. Many references can be found to the use of ultrasound methods in different types of board to evaluate different properties. The elastic properties of particle board have recently been studied (Najafi et al. 2005) as well as variations in density within boards (Kruse et al. 1996). Similar studies can be found for oriented strand board "OSB" (Vun et al. 2003). Stress wave vibrations have also been used by some authors in OSB (Ross et al. 2003) and other wood-based panels (Han et al. 2006). Several non-destructive methods have been used to estimate the physical and biological aging of particle and fibre boards (Bobadilla et al. 2009). The aim of this study is to examine non-destructive and portable methods to estimate the physical and mechanical properties of oriented strand board and its relation with the deterioration of the material during a laboratory aging test.

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MATERIAL TESTED

184 pieces of OSB 3 board (type 3 according to the EN 300:2007 standard) were tested, at three different thicknesses, 12, 15 and 18 mm. The determination of dimensions and preparation of the test samples were performed according to European standards EN 326-1:2010, EN 325:1994 and EN 300:2007. The panels tested were acquired in the Spanish market, but they were manufactured by the French company Kronofrance.

2. METHODOLOGY

3.1 Aging and conditioning

According to the European standards, conditioning was performed before all of the tests in a climate chamber at 20 ± 2°C temperature and 65 ± 5 % relative humidity. The moisture content was measured using the oven drying method, according to EN 322:1994.
Aging tests to evaluate the loss of properties were conducted based on the European standard EN 321:2002. The physical aging test performed, consists of three "one week" cycles of water immersion (20° C, 72 hours), cold (-12° C, 24 hours) and heat (70° C, 72 hours). All destructive and non-destructive physical and mechanical tests were performed before and after each "one week" aging cycle.

3.2 Test sequence

First of all, non-destructive tests were performed on all specimens after the conditioning of the samples. A quarter of the sample (46 specimens) were then separated in order to conduct destructive testing. The remaining sample (138 specimens) were subjected to the aging sequence. After the first aging cycle, another quarter (46 samples) was separated for non-destructive and destructive testing. The same operation was performed after each of the three aging cycles, always with the same number of specimens (46).

3.3 Density

Each specimen of wood-based board was weighed. Overall density was determined by dividing the total mass of each piece by its volume, based on the standard EN 323:1994. The results of density measurements, as well as the rest of the data obtained, are shown in **Table 1.**

3.4 Bending strength and Young modulus

According to EN 310:1994 standard methodology, bending tests were carried out in order to obtain bending strength (MOR) and the modulus of elasticity (MOE). The results of these mechanical parameters are also shown in **Table 1.**

3.5 Ultrasound velocity tests

Ultrasound tests consist of generating an ultrasonic frequency wave and emitting this across the zone to be inspected, from a transmitter-sensor to a receiver-sensor.
In this research project, ultrasonic wave propagation velocity was registered using Sylvatest-Duo equipment, (manufactured by Concept Bois Structure, Switzerland) that emits an ultrasonic wave of 22 kHz. The time it takes the wave to pass between the two transducers is recorded to compute propagation velocity. Pre-drilled contact holes are necessary in this case, so the test specimens must be drilled. In the test procedure the boards are placed on two supports with soft polyurethane pillows.
Ultrasound velocity measurement was carried out on the 500 mm longitudinal direction of each test specimen from edge to edge, as shown in **Figure 1.1**, and also at an angle of 45 degrees with both

sensors in the face of the board (**Figure 1.2**). The results of the edge to edge measurements are shown in **Table 1.**

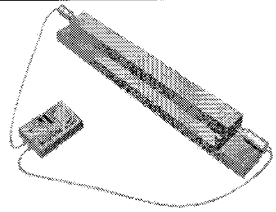

Figure 1.1

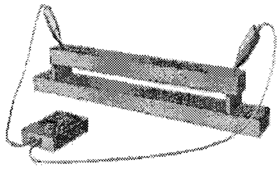

Figure 1.2

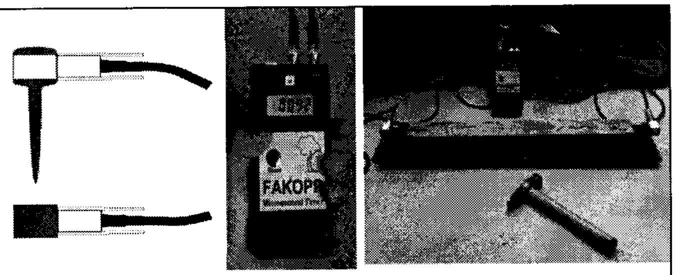

Figure 2

Figure 1.1, 1.2 and 2.- Ultrasonic end to end and 45° angle measurements. Stress wave velocity tool and edge to edge stress wave velocity measurement.

3.6 Stress wave velocity tests

In this case the equipment, a Microsecond timer (manufactured by Fakopp Enterprise, Hungary) is able to measure the transit time of a stress wave of approximately 2 Hz between two transducers, defining a line across the length of the board sample. The stress wave – induced by tapping one of the sensors with a hammer – travels in a straight line to the opposite sensor, and the equipment registers the time it takes the wave to pass between the two transducers. Pre-drilled contact holes are not necessary because this equipment has its transducers mounted directly on metal spikes, which provide direct contact points when the hammer is used to hit the transducers into the specimen. As in the previous case, in this test procedure the boards are placed on two supports with soft polyurethane pillows.

Determination of the edge to edge Stress wave velocity is performed using the equipment shown in **Figure 2**.
Using the board's length ("s" in meters *m*) and the time ("t" in seconds *s*), the wave velocity (V, in *m/s*) can be calculated by means of the equation (1):

$$\mathbf{V} = \frac{\mathbf{s}}{\mathbf{t}} \qquad (1)$$

Where: V= velocity, s= board length, t= time

The results of these end to end measurements are also shown in **Table 1**.

4. RESULTS AND DISCUSSION

4.1 General results:

Table 1.- The general results for density, MOE, MOR, ultrasound velocity (Vus) and stress wave velocity (Vsw).

Board Thickness	Aging Cycle	**Density** [kg/m^3]		**MOE** [N/mm^2]		**MOR** [N/mm^2]		**Vus** [m/s]		**Vsw** [m/s]	
		Mean	**CoV**	**Mean**	**CoV**	**Mean**	**CoV**	**Mean**	**CoV**	**Mean**	**CoV**
12	No Aging	645.9	7.6	4267.5	16.3	24.7	18.3	2883.8	3.6	2601.2	4.2
	1st Aging Cycle	522.5	6.9	2302.1	12.3	15.8	14.4	2506.2	3.6	2422.5	2.5
	2nd Aging Cycle	505.2	4.4	1515.3	17.1	10.7	17.5	2337.1	4.0	2259.6	3.2
	3rd Aging Cycle	482.2	3.7	1172.1	13.3	7.0	15.9	2232.2	3.9	2186.4	4.7

15	No Aging	607.3	3.4	5855.8	8.4	33.6	12.4	3617.4	2.2	3245.9	2.4
	1st Aging Cycle	538.3	5.1	2903.8	15.4	22.2	24.8	3272.8	4.3	3052.8	3.9
	2nd Aging Cycle	508.3	3.7	2367.7	9.7	17.7	10.9	3154.8	4.4	2991.5	4.0
	3rd Aging Cycle	483.2	3.1	1079.3	9.9	12.3	11.3	3078.3	4.8	3017.1	4.0
18	No Aging	598.6	2.8	3773.5	8.1	22.9	8.6	2780.6	3.4	2477.9	3.0
	1st Aging Cycle	531.6	5.8	2077.5	9.3	13.4	9.5	2366.7	6.7	2326.2	4.2
	2nd Aging Cycle	499.1	2.9	1777.0	11.1	11.7	12.2	2306.7	3.4	2244.0	2.8
	3rd Aging Cycle	493.3	4.3	1642.3	15.2	10.7	21.3	2292.1	4.5	2227.4	3.8

Note: Density (kg/m^3), MOE (N/mm^2), MOR (N/mm^2), Vus (ultrasonic wave velocity m/s), Vsw (Stress wave velocity m/s), CoV: Coefficient of variation (%).

4.2 Aging assessment and trend lines

Figure 3 shows the evolution of the different parameters in percentage terms, for destructive and non-destructive testing during the aging cycles of the boards.
A clear parallel can be seen between the loss of physical and mechanical properties and the propagation velocities recorded using ultrasound and a stress wave.

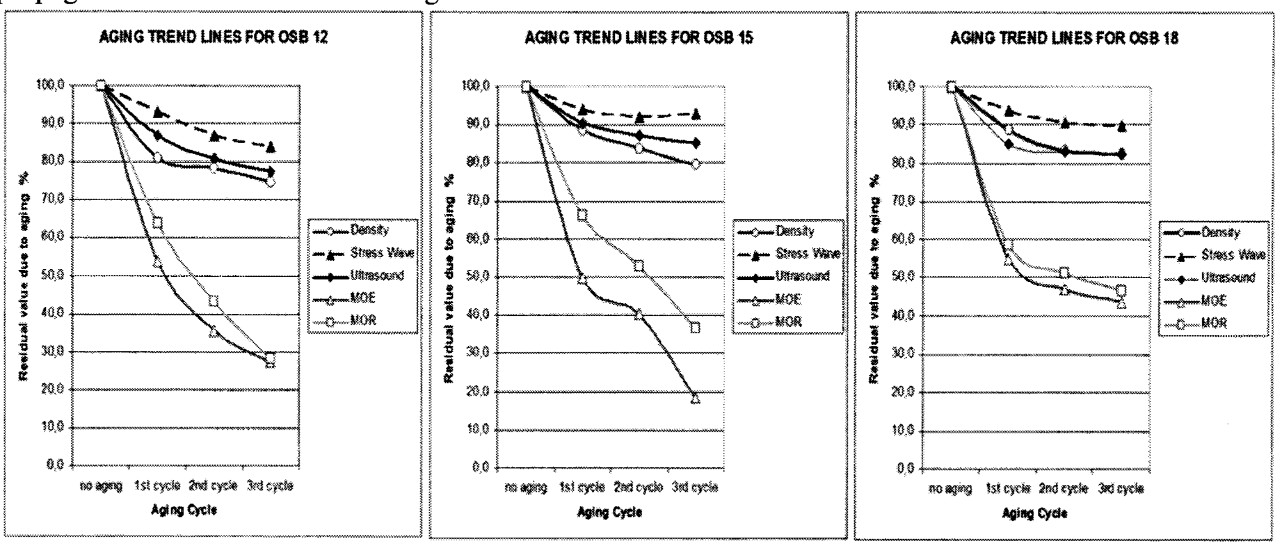

Figure 3 The evolution with aging of physical, mechanical and non-destructive measurements in 12, 15 and 18 mm boards.

Although the various board thicknesses show slightly different results, it can be concluded in general that declines of 20% in ultrasound velocity or 10-15% of stress wave velocity show losses of density of the same order (approximately 20-25%), and much higher losses of strength and elasticity (65-70%).
Loss of velocity can be therefore used to estimate the deterioration of a board.

4.3 Regression models

The regression models used to estimate the physical (density) and mechanical properties (strength and elasticity) using ultrasound and stress wave propagation velocity are shown below.
Assumptions of normality, homoscedasticity and linearity were made for all models.

A general equation (2) is presented:

$$\Pr = B \times Vel + C \times Z_{12} + D \times Z_{15} + E \qquad (2)$$

where "Pr" is the property estimated. B, C, D and E are constants and can be found in Tables 2 and 3 for ultrasound and stress wave velocity, respectively.

Table 2.- Models used to estimate density, MOR and MOE using Ultrasound velocity.

Pr	B	C	D	E	R^2 %
Density	0.210658	13.0875	170.509	14.842	74
MOR	0.025452	-1.6503	-14.68	-47.1166	77
MOE	5.00241	-299.755	-3460.7	-9835.03	75

Note: Density (kg/m^3), MOE (N/mm^2), MOR (N/mm^2), V (ultrasonic wave velocity m/s), Z12= 1 and Z15= 0 for 12mm thick board and Z15= 1and Z12= 0 for 15 mm thick board, Z12=0 and Z15=0 for 18 mm thick board.

Table 3.- Models to estimate density, MOR and MOE using Stress wave velocity.

Pr	B	C	D	E	R^2 %
Density	0.328123	0.522742	-244.073	-221.367	69
MOR	0.0387162	-1.59176	-22.6334	-74.7963	66
MOE	7.36765	-278.755	-4839.57	-14714.8	59

Note: Density (kg/m^3), MOE (N/mm^2), MOR (N/mm^2), V (Stress wave velocity m/s), Z12= 1 and Z15= 0 for 12mm thick board, Z15= 1 and Z12= 0 for 15 mm thick board, Z12=0 and Z15=0 for 18 mm thick board.

4.4 The relationship between edge to edge and 45 ° measures

Due to the impossibility of conducting edge to edge measurements on the boards on site, 45 degree measurements on the face of the board were made, as shown in Figures 1 and 2. These measurements show statistically significant differences with both ultrasound and stress wave, although the latter are more pronounced.

In order to use the previous models with the new 45 degrees measurements, the authors propose the following general regression model equation (3):

$$V_0 = A \times V_{45} + B \tag{3}$$

Where: Vo is the edge to edge velocity in m/s and V_{45} is the 45° velocity in m/s.

The constants A and B and the determination coefficients can be found in Table 4.

Table 4.- *Models to estimate end to end velocity from the 45° velocity.*

Vo	A	B	R^2 %
Ultrasound	0.986291	-7.30654	89
Stress wave	0.967319	-131.196	84

Note: *Vo (Edge to edge wave velocity m/s)*

As can be seen in the models shown, differences are more pronounced in the measurements made with stress wave equipment, at approximately 6% above average at 45 degrees, compared with 2% above average with ultrasound.

5. CONCLUSIONS

There is a strong statistical relationship between the decline in physical and mechanical properties and the non-destructive values (wave velocity) obtained during the aging process of the boards.

In almost all cases there are statistically significant differences between the different aging cycles for the parameters measured, using destructive and non-destructive testing. Nevertheless, these differences are more prominent in the early stages of aging, so that at first deterioration is greater. Exceptions to these significant differences always occur in the later aging stages, cycles 2 and 3.

The state of deterioration of a board and its remaining properties can be estimated from detected loss of velocity. This is particularly useful to detect possible damaged elements in building construction.

In the same way as with particle and fibre boards (Bobadilla et al. 2009), the best general predictive models were obtained with ultrasound, followed closely by the stress wave technique. The choice of either method depends on the availability of equipment and economic possibilities.

Measurements on the face of the board, with sensors at a 45 degree angle to the surface, can be performed in situ. In this case wave velocity will be slightly higher, between 2% on average for ultrasound and 6% on average for stress wave. The corresponding correction model to estimate the physical and mechanical properties has therefore to be used. Here, contrary results were obtained with particle and fibre boards, with lower speeds when taking 45 degree measurements (Bobadilla et al. 2009).

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